A bat survey in State Forests on the south-west slopes region of New South Wales with suggestions of improvements for future surveys

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ABSTRACT

Ten State Forests on the south-west slopes of New South Wales were surveyed for bats at 39 forest sites and 24 water-bodies using ultra-sonic bat detectors, harp-traps, mist-nets and trip-lines. Thirteen species of bats were recorded for the region. Many species were widespread, with six of the 13 species recorded at more than 50% of sites; however four occurred at less than 20% of sites. Each State Forest sampled supported at least eight species. The species of bats present were representative of the biogeographical region of the study area, lying in the transitional zone between moist climates of the east and arid environments to the west. Within the range of elevations sampled (390–1 419 m), *Chalinolobus gouldii, Vespadelus vulturnus, Mormopterus planiceps* Ip and *Scoforepens balstoni* were either absent or maintained lower activity levels above 1000 m. Bat activity and species richness was also low in forests typical of the most extreme climate (Snow Gum/Black Sallee), however no differences were found between forests with other floristic associations. Structural complexity appeared more important, as it was related to greater activity levels and higher species richness. Targetting water-bodies increased the efficiency of our survey as the number of bat passes recorded over water-bodies was three times greater than at forest sites. The use of Delay Switches revealed temporal differences in activity for a number of species. It is suggested that bat surveys should attempt to sample the entire night and only compare activity recorded in the same time period.

INTRODUCTION

Bats are an important contributor to the regional diversity of mammal species and it is now recognized that a variety of sophisticated methods are required to produce complete species inventories for this group (Schulz and de Oliveira 1995). The present study area of the south-west slopes region of New South Wales is expected to support a high biodiversity as it spans regions along the western edge of the Great Dividing Range with moist, dissected highland plateaus and drier, lower elevations of the western slopes (Caughley and Gall 1985). Extensive high altitude forests adjoin Kosciuszko National Park, while the forests of the lower slopes are now highly fragmented as a result of clearing for agriculture and pine plantations. Fragmentation of native vegetation has negatively affected the species richness of herpetofauna on the south-west slopes (Caughley and Gall 1985).

No extensive surveys for bats have been carried-out in this area and fauna surveys in general are few (Lunney *et al.* 1995). Surveys for bats in adjacent biogeographic regions have found a decrease in bat species diversity from the moist, forested east coast to the dry open woodlands of the west. Seventeen species were recorded on the south coast of New South Wales near Bega (Lunney and Barker 1986), compared to 13 species in remnant vegetation of the northern plains region of Victoria (Lumsden *et al.* 1995) and 11 and eight species further west in semi-arid regions of Victoria (Lumsden and Bennett 1995a) and the Willandra Lakes of New South Wales (Tidemann 1988), respectively.

This paper outlines a survey of bat species in the south-west slopes region of New South Wales and discusses possible environmental factors that may influence the distribution and abundance of bats in this region. As a variety of approaches are used in bat surveys and technological aids continue to be developed, we suggest a number of improvements to the design of surveys, particularly the use of ultra-sound activated Delay Switches.

METHODS

Study area

The study area ranges from extensive, high altitude forests bordering Kosciuszko National Park in the east to isolated and drier tracts of forest growing at lower altitudes in the west (Fig. 1). The region and land use practices are described in detail by Kavanagh and Stanton (1998) (see also Caughley and Gall 1985). Floristically, forests range from pure or mixed forests of Snow Gum *Eucalyptus pauciflora*, Black Sallee *Eucalyptus*

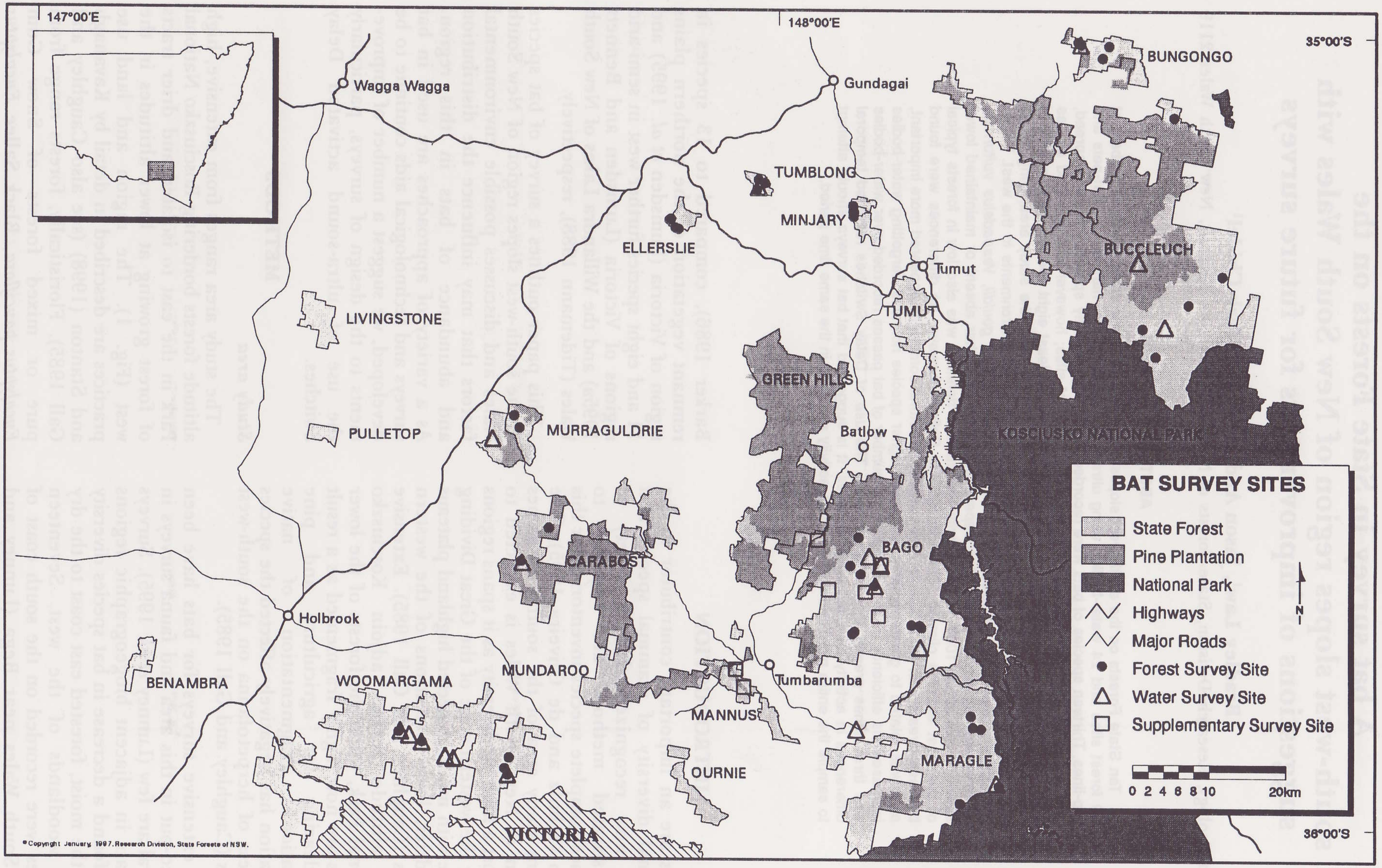

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Figure 1. Map of the study area showing the distribution of forest and water survey sites and supplementary sites (opportunistic harp-trapping only).

stellulata, Alpine Ash *Eucalyptus delegatensis* and Mountain Gum *Eucalyptus dalrympleana* at high, wet altitudes in the east to Narrow-leaved Peppermint *Eucalyptus radiata* and Red Stringybark *Eucalyptus macrorhyncha* at drier mid-altitudes. Various woodland species (e.g., Apple Box *Eucalyptus bridgesiana*, Long-leaved Box *Eucalyptus goniocalyx*, Eurabbie *Eucalyptus globulus bicostata*) dominate at lower altitudes further west.

Field sampling

Bats were surveyed in January, February and March 1995 and avoided periods of high wind, heavy rain and the full moon. State Forests were surveyed at 39 forest sites (Fig. 1), with a concentration in the eastern high altitude State Forests (Bago, Maragle and Buccleuch) where commercial forestry is most intense and forests are extensive.

Bats were surveyed using harp traps (Tidemann and Woodside 1978) and ultra-sonic detectors (Anabat II — Titley Electronics). Most sites were sampled with two harp traps placed within 200 m of each other for two consecutive nights (four trap-nights — 26 sites, 3 trap-nights 8 sites, two trap-nights 5 sites), a length considered to be an efficient sampling period for bats (Richards 1992). At the same time and within 50 m of the two harp-traps, one ultra-sonic bat detector was placed on the ground with the microphone oriented at a 45°C angle to remotely sample bat calls (see below). Where possible, the position of detectors was changed to point along the flyway for one night and on the next at a perpendicular angle into the vegetation. Sites were not selected at random, but were chosen to target bat fly-ways where trapping success could be maximized. Harp-traps were cleared each morning and bats were released near the point of capture. To maximize the species inventory for a forest, supplementary trapping targetted water-bodies such as forest dams and creeks in addition to sites located along flyways within forests. Bat activity is often concentrated around water-bodies and one species, *Myotis macropus* (formerly *M. adversus*), specializes in foraging at such sites (Dwyer 1970). Depending on the nature of the site, water-bodies were sampled using either mist-nets (15 sites), trip-lines (5 sites) or harp-traps (4 sites). One bat detector was successfully deployed at 20 of these sites. Water-bodies were monitored from dusk for up to 4 h. At least one water-body was sampled in all State Forests, except for Ellerslie and Minjary SFs, where none was present.

Ultra-sonic detection

Detectors were connected to a Delay Switch (Titley Electronics) and a cassette-recorder (Realistic CTR-76). Delay switches facilitate remote sampling by switching the recorder on at the sound of a high frequency call of an echolocating bat and down-loading the call, time and a calibration tone. This device improves inventory work as the entire night can often be sampled and recorded onto one side of a 45 minute cassette.

Bat passes were identified using zero-crossing analysis and Anabat Software (Version 5), by comparing call traits with reference calls recorded from captured bats released during the survey and those provided with the Anabat software. A bat pass was defined as a sequence of three or more pulses. Pulses separated from another sequence by a period of five seconds were considered to be separate passes. This method allowed scattered sequences, where intermittent pulses (>2) are not separated by more than five seconds, to be recognized as a single pass. If constant activity was recorded, a single pass was arbitrarily defined as 15 seconds (i.e., one full display screen using Anabat 5). Although this method underestimates the number of bat passes when there is continuous activity, the standard unit of time allows consistency. It is also important to remember that multiple passes from a single bat are not distinguished from single passes from many bats, however a useful index of activity in an area is still derived.

Call traits used for identification included minimum frequency, average characteristic frequency, pulse duration, time between pulses and shape. The calls of some species were difficult to distinguish. No attempt was made to distinguish *Nyctophilus gouldi* from *N. geoffroyi* on the basis of calls. Only clear, distinct calls of *Vespadelus regulus* and *V. darlingtoni* could be allocated to species level as some overlap occurred between their calls. Poor quality calls were pooled as *V. darlingtoni/regulus*. Finally, any remaining poor quality or brief calls that were not possible to identify to species were grouped as unidentified bat passes and incorporated into measures of total bat activity. The presence of feeding attempts (feeding buzz) was assessed by listening to replays of calls and inspecting call characteristics such as increased pulse rate and drops in the terminal frequency of calls (Jones and Corben 1993).

Habitat characteristics

At each site the broad forest type was recorded in consultation with forest type maps (Forestry Commission of New South Wales unpubl. maps — Hardwoods District, Tumbarumba). In addition, details concerning structural attributes of the forest were recorded by eye. Canopy cover was scored as nil (0%), one (1–33%), two (34–67%) or three (68–100%). The number of vegetation layers was scored as one (e.g., canopy only), two (e.g., shrub or regenerating canopy layer plus overhead canopy) or three (e.g., emergents, canopy and shrub layer). Average canopy height was estimated in metres. Site altitude was taken from 1:25000 topographic maps.

Analysis

At each site, an index of bat abundance was calculated for each species by summing all captures in the harp-traps over two nights of sampling and expressing this index as bats caught per trap-night. An independent index of activity was calculated for each species by summing the number of bat passes for each species per site. For comparisons of activity between sites, the index was calculated as the number of bat passes in the first hour after sunset. This is because not all sites were sampled for the full night (38% of sites), due to high levels of bat activity, high frequency sounds of insects triggering the Delay Switch or deteriorating weather conditions during the night. The maximum period of sampling was used to produce species inventories for each site as some species of bats were most active later in the night (see Results). For comparisons of activity between different environments, observations of each species were grouped into five foraging guilds. These follow those proposed by Kutt (1995) and were modified for the present study area as follows: guild 1 (*Nyctinomus australis, Mormopterus planiceps* long penis form -lp), guild 2 (*Miniopterus schreibersii, Chalinolobus gouldii*), guild 3 (*Falsistrellus tasmaniensis, Vespadelus darlingtoni*), guild 4 (*Chalinolobus morio, Vespadelus vulturnus, Vespadelus regulus*) and guild 5 (*Nyctophilus* spp.).

Parametric tests (t-Tests) for differences between means ($\log_{10}$ transformed data) were used unless departures from the normal distribution of the data were considerable. In these cases, equivalent non-parametric tests (Mann-Whitney; Kruskal-Wallis) were used. Means are presented with standard errors. Where sample sizes were greater than five, chi-square tests were used to test for differences in the frequency of occurrence of bat species at forest sites and water bodies and for departures from parity in sex-ratios.

RESULTS

Methodological considerations

The positioning of remote ultra-sonic detectors at 15 sites where detectors faced both along tracks and off tracks had no effect on the number of bat species recorded, total bat activity or the activity of any individual species or foraging guilds (Paired T-tests, $P > 0.05$). The only effect of detector positioning was on the number of feeding buzzes recorded. On average, more feeding attempts (Paired T-test: $t = 3.01_{(14)}$, $P = 0.01$) were recorded on tracks (nine per hour) than off tracks (one per hour). Identification of calls to species level was generally easier on tracks as bats flew directly towards the microphone, thus improving the quality and the length of the call recorded.

Analysis of temporal bat activity patterns indicated that activity (total number of bat passes) and feeding activity (total number of feeding buzzes) was concentrated in the first hour after sunset, although lower levels of activity continued throughout the night (Fig. 2). Only three out of nine species conformed directly to this pattern of low activity late in the evening. Notable exceptions included *C. morio, C. gouldii* and to a lesser extent *V. vulturnus*, which were most active early in the evening, but experienced peaks seven to eight hours later (Fig. 2). In addition, the activity of species that were infrequently detected was found to be more evenly spread throughout the night, although sample sizes for these were much lower (Fig. 2). Thus although most activity occurs early in the evening, increasing sampling time increases the chance of recording *C. morio, V. vulturnus* and rare species, such as *F. tasmaniensis*. This effect resulted in more species being detected when the whole night was sampled compared to the first hour after sunset (Paired T-test: $t = 3.67_{(9)}$, $P < 0.01$, $n = 10$ State Forests). Because not all sites were sampled for the full length of the night, only calls recorded in the first hour of the night have been used in comparisons of bat activity. For comparisons of species richness the maximum sampling at each site, which averaged 7.1 ± 0.6 h, was used.

Trapping and ultrasonic detection each have their own biases (Law 1996). Although an index of activity can be derived from each, we found that the number of bats caught per trap-night was not correlated with the total number of bat passes recorded ($r = 0.05$, $P = 0.77$). Each method was therefore used independently as an index of activity. In addition, the number of feeding buzzes per

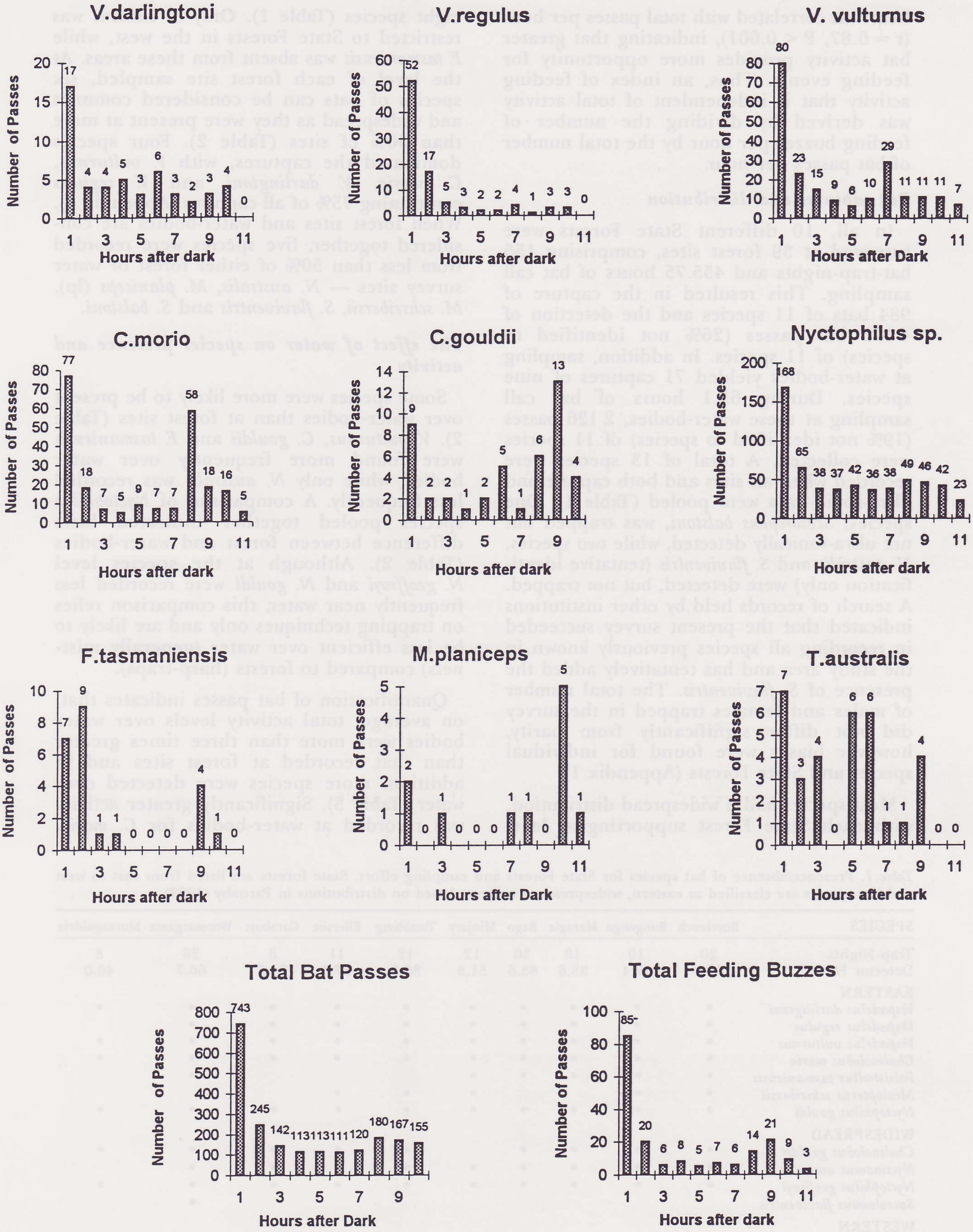

Figure 2. Nightly activity patterns for bat species identified by ultra-sonic sampling in the study area. Activity is shown as the number of passes in each hour after sunset. Only those sites where ultra-sonic sampling occurred for the entire night (n = 24) and were located within forest (i.e., not over water) are shown.

hour was correlated with total passes per hour ($r = 0.87$, $P < 0.001$), indicating that greater bat activity provides more opportunity for feeding events. Thus, an index of feeding activity that is independent of total activity was derived by dividing the number of feeding buzzes per hour by the total number of bat passes per hour.

Bat captures and distribution

In all, 10 different State Forests were surveyed at 39 forest sites, comprising 155 bat-trap-nights and 455.75 hours of bat call sampling. This resulted in the capture of 984 bats of 11 species and the detection of 4 195 bat passes (26% not identified to species) of 11 species. In addition, sampling at water-bodies yielded 71 captures of nine species. During 65.1 hours of bat call sampling at these water-bodies, 2 126 passes (19% not identified to species) of 11 species were collected. A total of 13 species were recorded when all sites and both capture and ultra-sonic data were pooled (Table 1). One species, *Scotorepens balstoni*, was trapped but not ultra-sonically detected, while two species, *N. australis* and *S. flaviventris* (tentative identification only) were detected, but not trapped. A search of records held by other institutions indicated that the present survey succeeded in recording all species previously known in the study area and has tentatively added the presence of *S. flaviventris*. The total number of males and females trapped in the survey did not differ significantly from parity, however biases were found for individual species and State Forests (Appendix 1).

Most species had a widespread distribution, with each State Forest supporting at least eight species (Table 1). Only *S. balstoni* was restricted to State Forests in the west, while *F. tasmaniensis* was absent from these areas. At the level of each forest site sampled, six species of bats can be considered common and widespread as they were present at more than 50% of sites (Table 2). Four species dominated the captures, with *V. vulturnus*, *C. morio*, *V. darlingtoni* and *V. regulus* constituting 75% of all captures (Appendix 1). When forest sites and water-bodies are considered together, five species were recorded from less than 50% of either forest or water survey sites — *N. australis*, *M. planiceps* (lp), *M. schreibersii*, *S. flaviventris* and *S. balstoni*.

The effect of water on species presence and activity

Some species were more likely to be present over water-bodies than at forest sites (Table 2). *V. vulturnus*, *C. gouldii* and *F. tasmaniensis* were found more frequently over water bodies, while only *N. australis* was recorded less frequently. A comparison of *Nyctophilus* species pooled together indicated little difference between forest and water-bodies (Table 2). Although at the species level *N. geoffroyi* and *N. gouldi* were recorded less frequently near water, this comparison relies on trapping techniques only and are likely to be less efficient over water (generally mist-nets) compared to forests (harp-traps).

Quantification of bat passes indicates that, on average, total activity levels over water bodies were more than three times greater than that recorded at forest sites and in addition, more species were detected over water (Table 3). Significantly greater activity was recorded at water-bodies for *C. morio*,

Table 1. Presence/absence of bat species for State Forests and sampling effort. State forests are listed from east to west and bat species are classified as eastern, widespread or western, based on distributions in Parnaby (1992).

SPECIES	Buccleuch	Bungongo	Maragle	Bago	Minjary	Tumblong	Ellerslie	Carabost	Woomargama	Murraguldrie
Trap-Nights	20	10	18	30	12	12	11	8	26	8
Detector Hours	57.4	19.4	33.6	83.6	51.5	38.5	47.0	24.0	60.7	40.0
EASTERN										
Vespadelus darlingtoni	*	*	*	*	*	*	*	*	*	*
Vespadelus regulus	*	*	*	*	*	*	*	*	*	
Vespadelus vulturnus	*	*	*	*	*	*	*	*	*	*
Chalinolobus morio	*	*	*	*	*	*	*	*	*	*
Falsistrellus tasmaniensis	*	*	*	*	*				*	
Miniopterus schreibersii	*	*			*	*	*			
Nyctophilus gouldi	*	*	*	*	*	*	*	*	*	*
WIDESPREAD										
Chalinolobus gouldii	*	*	*	*		*	*	*	*	*
Nyctinomus australis	*	*	*	*	*	*	*	*	*	
Nyctophilus geoffroyi	*	*	*	*	*	*	*	*	*	*
Saccolaimus flaviventris									*	
WESTERN										
Mormopterus planiceps (l.p.)	*	*				*		*	*	*
Scotorepens balstoni										*
TOTAL	11	11	9	9	9	10	9	9	11	8

Table 2. Percentage occurrence of bat species, from trapping and detection records combined, at forest sites and water bodies. Occurrence of *N. geoffroyi* and *N. gouldi* (in brackets) is based on trapping results only as ultra-sonic calls of these species could not be distinguished. Ultrasonic calls of these species are pooled under *Nyctophilus* spp. Differences in the frequency of occurrence was tested using X^2 values (* = significant at $P < 0.05$). n = number of site sampled.

Species	Forest		Water Bodies		Test (df = 1)	
	%	n = 39	%	n = 20	X^2	P
Nyctophilus spp.	87	34	94	15	0.50	P = 0.48
C. morio	72	28	81	13	0.54	P = 0.46
V. vulturnus	64	25	94	15	5.02	P < 0.05 *
V. regulus	69	27	81	13	0.83	P = 0.36
(*N. geoffroyii*)	84	37	6	1	—	—
V. darlingtoni	67	26	75	12	0.37	P = 0.54
(*N. gouldi*)	55	24	13	2	—	—
N. australis	41	16	6	1	6.43	P < 0.01 *
C. gouldii	33	13	88	14	13.30	P < 0.001 *
F. tasmaniensis	28	11	56	9	3.90	P < 0.05 *
M. planiceps (l.p.)	15	6	19	3	0.09	P = 0.76
M. schreibersii	10	4	19	3	0.74	P = 0.39
S. balstoni	3	1	0	0	—	—
S. flaviventris	0	0	6	1	—	—

Table 3. Mean (± standard error) number of bat passes in the first hour after sunset recorded at forest sites and over water-bodies. Differences are tested using T- or Mann-Whitney U tests (* = significant at $P < 0.05$).

Species	Forest (n = 39)	Water (n = 20)	Test (df = 53)	
Total Passes/Hour	24.50 ± 4.03	79.80 ± 14.30	t = 2.33	P < 0.05
Feeding Index	0.14 ± 0.30	0.09 ± 0.02	U = 277.5	P = 0.52
Species Richness	4.28 ± 0.24	5.31 ± 0.36	t = 4.05	P < 0.001 *
V. vulturnus	4.79 ± 1.75	16.88 ± 6.06	t = 3.42	P < 0.01 *
V. regulus	1.94 ± 0.55	5.19 ± 2.05	t = 1.80	P = 0.08
V. darlingtoni	1.06 ± 0.37	6.77 ± 2.28	U = 95.5	P < 0.01 *
C. gouldii	1.37 ± 0.99	10.22 ± 3.56	t = 4.92	P < 0.01 *
C. morio	1.23 ± 0.72	4.94 ± 1.71	t = 3.41	P < 0.01 *
F. tasmaniensis	0.94 ± 0.68	1.81 ± 0.75	t = 1.91	P = 0.06
M. schreibersii	0.35 ± 0.22	0.34 ± 0.31	t = 0.08	P = 0.94
M. planiceps (l.p.)	0.03 ± 0.02	0.66 ± 0.50	U = 287.0	P = 0.43
N. australis	0.26 ± 0.12	0.38 ± 0.38	t = -0.19	P = 0.85
Nyctophilus spp.	5.36 ± 1.90	7.63 ± 2.18	t = 1.56	P = 0.13

C. gouldii, *V. darlingtoni*, *V. vulturnus* and there was also a strong trend for *F. tasmaniensis* in this direction. No species showed higher levels of activity at forest sites compared to water-bodies.

The effect of environmental variables on activity

Elevation: Site elevation ranged from 390 to 1 419 m, however elevation was not correlated with total number of bats trapped ($r = -0.18$, $P = 0.25$) and only weakly negatively correlated with the total number of passes detected ($r = -0.34$, $P < 0.05$). This weak correlation probably reflects the avoidance of high altitudes by some species. Above 1 000 m ($n = 17$), fewer passes ($U = 51.5$, $P < 0.01$) and trap records ($t = -2.68_{(42)}$, $P = 0.01$) of *V. vulturnus* were evident. No passes of *C. gouldii* were detected above 1 000 m, although it was trapped at a similar rate to low elevations ($U = 323$, $P = 0.15$). *M. planiceps* was not caught in harp-traps above 1 000 m and *S. balstoni* was trapped only once at an altitude of 480 m. Elevation had no effect on the activity of the remaining species nor the total rate of feeding of all species.

Forest Type: Five broad forest types were sampled for bats in the study area. Forest type had no detectable effect on the number of bats trapped, the level of bat activity or the amount of feeding activity recorded (Table 4). Furthermore, the type of forest sampled had no effect on the activity recorded for five foraging guilds as derived from either total bats trapped or passes detected (Kruskall-Wallis tests — $P > 0.1$). However, all of these measures showed a strong trend for lower bat activity in Snow Gum and Black Sallee forests and a significantly lower number of species (Table 4). It should be noted that only two sites supporting this forest type were sampled.

Table 4. Comparison of number of bats trapped, passes/hr (1 hour after sunset), feeding buzzes/hr (1 hour after sunset) and species richness (entire night) between five major forest types present in the study area. An index of feeding was derived by dividing the number of feeding buzzes by the number of bat passes. aA — Alpine Ash, aA/mG — mixed Alpine Ash and Mountain Gum, snG/mG/nPM — mixed Snow Gum, Mountain Gum and Narrow-leave Peppermint, snG/SL — Snow Gum or Black Sallee, Woodland — includes Red Stringybark, Narrow-leaved Peppermint, Long-leaved Box, Eurabbie. Means ± SE are given, n = the number of sites. Differences are tested using Kruskal-Wallis tests (* = significant at P < 0.05).

	Forest Types					
	aA	aA/mG	snG/mG/nPM	snG/SL	Woodland	Test (DF = 4)
Bats/Trap-night	11.7 ± 9.7 (4)	4.5 ± 1.8 (6)	4.4 ± 1.5 (7)	0.7 ± 0.7 (2)	6.4 ± 1.5 (25)	H = 2.51, P = 0.64
Passes/Hour	11.3 ± 4.5 (3)	15.6 ± 3.9 (6)	34.5 ± 14.1 (6)	2.0 ± 2.0 (2)	26.7 ± 5.6 (21)	H = 6.79, P = 0.15
Feeding Buzzes/Hour	1.2 ± 0.2 (3)	3.1 ± 1.7 (6)	7.9 ± 5.2 (6)	0.3 ± 0.3 (2)	3.9 ± 1.3 (21)	—
Feeding Index/Hour	0.1 ± 0.1 (3)	0.2 ± 0.1 (6)	0.2 ± 0.1 (6)	0.1 ± 0.1 (2)	0.2 ± 0.1 (21)	H = 3.27, P = 0.51
Species Richness	7.0 ± 1.0 (3)	5.0 ± 0.6 (6)	6.7 ± 0.5 (6)	3.5 ± 0.5 (2)	6.6 ± 0.1 (21)	H = 10.29, P = 0.04*

Structural Attributes of Forests: To investigate the effect of forest structure on bats, sites were grouped into two categories for each of: 1. structural complexity — a single upper canopy layer (n = 11) or an upper canopy and lower shrub layer (n = 33); 2. canopy height — to reflect broadly the presence of forest (canopy ≥20 m, n = 14) or open woodland (canopy <20 m, n = 30); and 3. canopy cover — <25% (n = 33) or 26–50% (n = 11) cover. Forests with two vegetation layers supported significantly more species of bats (detecting: $t = 2.55_{(35)}$, $P < 0.05$; trapping: $t = 2.51_{(40)}$, $P < 0.05$) and greater total activity (detecting: $t = 1.91_{(35)}$, $P = 0.06$; trapping: $t = 3.60_{(47)}$, $P = 0.001$) than forests that lacked a lower shrub layer. On a foraging guild basis, greater activity in forests with two vegetation layers was apparent for guild 3 only (detecting: $t = 1.89_{(35)}$, $P = 0.07$; trapping: $t = 2.51_{(42)}$, $P < 0.05$). Guild 1 was not detected above forests with just a single vegetation layer. Canopy height and canopy cover had no significant effect on the number of bats trapped, passes detected or the rate of feeding for all species grouped together, five designated foraging guilds or total species richness (T-tests, $P > 0.1$). Calls of bats in foraging guild 2 were not detected in forests with a canopy height over 20 m, however, they were trapped in forests of a range of heights ($U = 203$, $P = 0.41$). This anomaly probably reflects sampling deficiencies resulting from the infrequent occurrence of guild 2, particularly of *C. gouldii* at high elevations (where taller forests grow in the study region) and *M. schreibersii* throughout the study area (Table 3).

Effects of Logging: In the more intensively harvested high altitude forests of Bago, Maragle and Buccleuch, the time since last logging ranged from 2 to 30 years with just one survey site having never been logged. No significant correlation was found between time since last logging and either the number of bats trapped ($r = -0.0006$), the number of calls detected per hour ($r = 0.19$) or total species richness ($r = 0.05$).

DISCUSSION

Bats of the South-west Slopes Region

The 13 species of bats recorded in this survey represent 33% of the native mammal species known to occur in the district (Kavanagh and Stanton 1998; Stanton and Anderson 1998). This number of species is identical to a bat survey in the nearby northern plains region of Victoria (Lumsden *et al.* 1995), with 10 species common to both surveys. Overall, the number of bats caught per trap-night in our survey (6.3) was higher than that reported (5.0) by Lumsden *et al.* (1995). Populations of some species were found to have biased sex-ratios (Appendix 1), a feature also noted in bat populations of semi-arid Victoria (Lumsden and Bennett 1995) and the A.C.T (Phillips *et al.* 1985). The significance of this is not yet known.

Six bat species were widespread on the south-west slopes, being recorded at more than 50% of sites. Four of these (*V. vulturnus, C. morio, V. darlingtoni* and *V. regulus*) represented 75% of all captures. Five species (*N. australis, M. planiceps* (lp), *M. schreibersii, S. flaviventris* and *S. balstoni)* were locally uncommon as they were recorded at less than 50% of either forest or water survey sites. It is interesting to note that *F. tasmaniensis*, listed as Vulnerable under the NSW *Threatened Species Conservation* Act 1995, was not one of these five. This species was recorded from five State Forests (Table 1) and it was present at 37% of the high altitude forest sites located in Bago, Maragle and Buccleuch (n = 19 sites). The trapping success at Maragle State Forest (1 per trap-night — Table 4) is greater than that reported in other published studies (0.05–0.3 per trap-night — Phillips *et al.* 1985; 0.03 per trap-night — Brown and Howley 1988), suggesting that the wet, high altitude forests could be an important habitat for *F. tasmaniensis* (Menkhorst and Lumsden 1995). Successful trapping of this species at Maragle SF suggests that this would provide an ideal location for more detailed ecological studies.

The presence of the widely distributed Yellow-bellied Sheath-tailed Bat *S. flaviventris* on the south-west slopes of New South Wales requires confirmation as only three calls of this species were recorded and the quality was not sufficient for a definite identification. This species is possibly a late summer migrant to southern Australia (Parnaby 1992; Lumsden and Menkhorst 1995a) — the period of this survey. Only one arid-adapted species (*S. balstoni*) was recorded in our survey and only a single individual was caught. We did not record the southern freetail bat *M. planiceps* (short penis), although it is known from River Red Gum forest near Narranderra 170 km further west (Law, unpubl. data). The Greater Long-eared Bat *Nyctophilus timoriensis* was not recorded in our survey and it appears to be confined to semi-arid areas of western New South Wales. It is known from only four records in Victoria (Lumsden 1994) and it is officially listed as Vulnerable in New South Wales. It was not recorded in a fauna survey adjacent to the western portion of Woomargama SF (Moore *et al.* 1992), nor in nearby surveys further west (Boss and Herr, pers. comm. — Charles Sturt University, Albury). The absence or rarity of these species from the south-west slopes is consistent with the study area lying in the transition zone between moist climates of the east and arid environments to the west (Caughley and Gall 1985).

It is possible that a further three species of bats could occur on the south-west slopes. The Little-red Flying Fox *Pteropus scapulatus* has been recorded east of Holbrook (Klomp and Marshall 1995) and is likely to be seasonally present. Camps of unidentified flying foxes were reported in the late 1970s and early 1980s on the Murrumbidgee River near Gundagai and adjacent to the Tumut River near Darbalara (unpubl. records of SFNSW, Research Division). The Eastern Horseshoe Bat *Rhinolophus megaphyllus* has been banded previously at Wee Jasper caves (CSIRO Wildlife Collection, Canberra), 9 km east of the study area. This is a species of moist climates and is generally considered to be common within its range where suitable caves occur. The South-West Slopes area is generally lacking in caves, as is evidenced by the low occurrence of the Common Bentwing Bat *M. schreibersii.* This species was most frequently recorded in Buccleuch and Bungongo State Forests, which are the closest State Forests to Wee Jasper caves and significant disused mines. Two horizontal mines were inspected and sampled for bats (Woomargama and Buccleuch State Forest) and another area known as the Tin Mine area (Woomargama) was sampled with detectors, but no cave-dwelling bats were found. The Large-footed Myotis *M. macropus* is another species that has been banded at Wee Jasper (CSIRO Wildlife Collection, Canberra) and recorded west of our study area over a billabong in Boomanoomana State Forest (Gall, unpubl. data) near the Murray River. It was not detected in our survey despite sampling 16 different water bodies, although most of these were not still pools in creeks known to be favoured by *M. macropus*. Still pools were uncommon in the area. Thus if present, each of the above species are likely to be restricted in distribution.

Factors influencing the distribution of bats on the south-west slopes

Lumsden and Bennett (1995a) classified bats in semi-arid Victoria as arid-adapted, mesic-adapted and those common to both. Bats from the south-west slopes of New South Wales appear to fit this classification based on moisture availability — dry (*S. balstoni*), mesic (*C. morio, V. darlingtoni, V. regulus, V. vulturnus, F. tasmaniensis,* and *N. gouldi*) and widespread (*N. geoffroyi, C. gouldii, N. australis* and *S. flaviventris*). However, *M. planiceps* (lp), listed as mesic adapted by Lumsden and Bennett (1995a), was more commonly recorded in western forests and was recorded only once in eastern forests in our survey. Surface water also plays an important role in influencing the distribution of bats at a local scale. Total levels of bat activity, especially for *C. morio, C. gouldii, V. darlingtoni, V. vulturnus* and *F. tasmaniensis,* and species richness were greater over water-bodies than in the forest. *F. tasmaniensis,* the most coastal of each of these species, was absent from all low altitude forests at the western edge of the study area, except for Woomargama SF. In this area, it was only recorded or trapped adjacent to water-bodies. A number of studies overseas have emphasized the importance of waterways as feeding habitat for bats because of the high levels of foraging activity detected (Thomas 1988; Rydell *et al.* 1994). Water-bodies are also used in winter as bats need to arouse from long-term torpor to replenish water supplies (Tidemann and Flavel 1987). These observations emphasize the importance of such areas as habitat regularly used by a number of species of bats.

Few other measured habitat features were related to either the number of bats trapped or the number of passes recorded. High elevations had low bat activity, an effect particularly noticeable in Snow Gum/ Black Sallee forests. It is not known whether altitude reduces the suitability of roost hollows or if it has a negative effect on insect populations. The species most affected by altitude were *C. gouldii, V. vulturnus* and *M. planiceps* (lp). A negative relationship with altitude for *V. vulturnus* has been reported elsewhere (Hoye 1991; Lumsden and Bennett 1995b). Elevation is also likely to have a negative effect on the dry-adapted *S. balstoni*, recorded from a single capture in this study. Excepting Snow Gum/ Black Sallee forests, forest type had no detectable effect on activity levels, although forests were not sampled equally and variability was high. A high overlap of species between vegetation types was also reported in Victoria (Lumsden and Bennett 1995a). Of the three structural attributes of forest measured, only the number of vegetation layers had a statistical effect. Forests with two vegetation layers supported more species and greater total activity than forests with a single vegetation layer. This was most pronounced for bat guilds that feed within the sub-canopy layer. These results provide support for the idea that the structural complexity of forests is of importance to bats (Glass 1993; Law 1996) and suggests that more quantitative measures of structural complexity would be of value in bat surveys.

There is evidence that some logging practices and frequent control burning lead to a simplification in structural attributes of forests (Catling 1991; Law 1996). Fire history was not recorded in the current survey, while logging history was highly variable and most areas have been logged more than once. The proportion of regrowth forest is generally high with logging intensity ranging from light selective logging to areas that experienced timber stand improvement treatment (Gay, pers. comm.). That bat activity was not correlated with logging history, together with records of feeding buzzes in a variety of regrowth forest types, implies that logging has little impact on bats. However, such analyses are limited as the survey was not designed to sample the intricate mosaic of logged and unlogged forest at a spatial scale appropriate to bats (Law 1996) or to record in any detail the availability of hollows.

Kavanagh and Stanton (1998) found that hollows suitable for arboreal mammals were uncommon in the south west slopes region, particularly in logged Alpine Ash *E. delegatensis* forests. Although logging is less intense in drier woodlands of the lower western slopes, past cutting for mining timbers, fuel and silvicultural treatment has typically left few hollows in such areas (Traill 1991, 1993), particularly on public land (Bennett *et al.* 1994). The relatively high bat activity we recorded in such woodlands suggests that either these studies have not adequately assessed hollow availability for bats or that roost preferences are flexible. Radio-tracking studies of bat roost preferences suggest that the latter is unlikely (see Law 1996). Despite the difficulty of estimating hollow availability for bats, we support the management recommendations of Traill (1993) for woodlands, particularly the retention and recruitment of large mature habitat trees and dead standing trees. In addition, habitat strips along or surrounding water-bodies would be valuable considering their influence on the local distribution of bats. Detailed research programmes are needed to test the effectiveness of such measures and whether further management prescriptions may be required.

The greatest conservation concern for bats in the region has been the extensive clearance and fragmentation of woodlands for agriculture. Caughley and Gall (1985) estimated that 95% of forests and woodlands in the greater south-west slopes region had been cleared. Such extensive clearing of woodlands is typical of other areas of New South Wales (Sivertsen 1993) and Victoria (Traill 1991). Fragmentation of woodlands in Victoria was thought to have little impact on the bat fauna (Lumsden *et al.* 1995). Although more detailed analyses in the present study region indicate that bat species richness in small remnants (< 10 ha) is comparable to extensive forests (>20 000 ha), some bat species are negatively affected (Law, unpubl. data — Research Division, SFNSW). The large number of bat species supported in each State Forest (>8 species) highlight the importance of these areas for bat conservation.

Some methodological suggestions for future surveys

Remote sampling with Delay Switches proved valuable for yielding a sample size of calls adequate for statistical analysis, a concern also expressed by Thomas and West (1989). This is of particular concern when analysis is undertaken at the species level or if the number of feeding attempts is to be compared between environments. Temporal differences in activity were also found. Although most activity is concentrated in the first hour after dark when bats leave their roost, some species show high activity peaks later in the evening. Peaks prior to sunrise have also been reported for *V. vulturnus*, *C. morio*, *V. regulus* and *F. tasmaniensis* in a trapping study in Tasmania (Taylor and O'Neill 1988). To avoid missing some species and thus to maximize a species inventory, sampling the entire night should be a priority. Most importantly, comparisons of bat activity between habitats must compare the same time period.

The positioning of detectors also needs to be considered in survey design. In our study, no difference was found between detectors facing along tracks and those facing off tracks. An exception was the greater number of feeding buzzes recorded on tracks, suggesting that flyways may be ideal bat feeding areas as well as commuting corridors. It is possible that track edges increase the feeding opportunities for bats. The effect of detector position should be tested in other forest types, as most of our sites (55%) were in open woodland rather than thick forest. Preliminary results from 20 year regrowth forests in Tasmania support our findings in that no difference was found in total activity between detectors on or off tracks (Duncan 1995). If these results are supported from additional areas, we suggest sampling on tracks. This is because in general, a better quality of call was recorded on tracks, presumably because bats flew along the flyways directly towards the microphone.

The higher levels of activity over water-bodies than in forest indicate that these habitats provide the best sites for producing a species inventory in the study region. Similar work is required in additional Australian environments, although support from studies undertaken overseas suggests that high levels of bat activity over water are likely to be a common pattern (Thomas 1988; Rydell *et al.* 1994).

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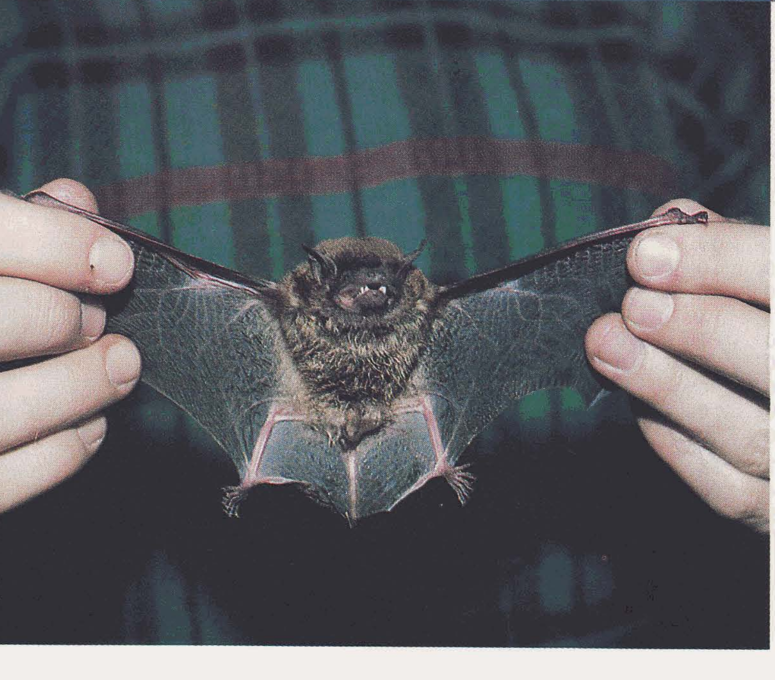
APPENDIX 1

The number of bats harp-trapped and sex-ratios of species in each State Forest sampled. Species are sorted in descending order of total numbers trapped for the survey. Probabilities are given for X^2 -tests to test whether sex-ratios depart from parity of (* = significant at P < 0.05). Bago, Carabost and Bungongo SF showed female-biased populations. By contrast, male-biased populations were present in Maragle and Tumblong SF. When data for all State Forests are combined, sex-biased populations are evident for *N. geoffroyi* (female), *F. tasmaniensis* (male), *M. planiceps* (male) and a strong trend in *C. gouldii* (female).

Species		Bago	Maragle	Buccleuch	Bungongo	Woomargama	Carabost	Murraguldrie	Ellerslie	Tumblong	Minjary	Total	X^2-Test
V. vulturnus	males	5	14	3	3	7	11	22	12	38	5	120	
	females	5	8	4	12	6	8	26	21	13	3	106	0.35
C. morio	males	5	42	16	8	8	10	7	0	5	1	102	
	females	22	26	18	5	11	7	5	1	2	1	98	0.78
V. darlingtoni	males	6	53	16	5	16	5	2	0	0	0	103	
	females	6	16	2	20	22	20	1	0	0	0	87	0.25
V. regulus	males	12	6	7	1	17	17	0	0	0	0	60	
	females	11	6	13	6	9	12	0	2	2	0	61	0.93
N. geoffroyii	males	1	2	9	0	6	6	8	3	2	2	39	
	females	19	4	1	1	13	18	7	3	3	2	71	<0.01*
N. gouldi	males	2	5	4	3	1	2	3	2	2	1	25	
	females	4	6	3	2	2	12	2	1	1	0	33	0.29
C.gouldii	males	0	1	0	1	1	4	4	1	2	0	14	
	females	0	1	0	1	1	17	6	0	0	0	26	0.06
F. tasmaniensis	males	1	18	0	0	0	0	0	0	0	0	19	
	females	0	0	1	1	0	0	0	0	0	0	2	<0.001*
M. planiceps	males	0	0	0	0	1	3	1	0	6	0	11	
	females	0	0	0	0	0	1	0	0	1	0	2	0.01*
M. schreibersii	males	0	0	0	0	0	0	0	0	0	0	0	
	females	0	0	3	1	0	0	0	0	0	0	4	—
S. balstoni	males	0	0	0	0	0	0	1	0	0	0	1	
	females	0	0	0	0	0	0	0	0	0	0	0	—
Totals	males	32	141	55	21	57	58	48	18	55	9	494	
	females	67	67	45	49	64	95	47	28	22	6	490	
X^2-Test		<0.001*	<0.001*	0.32	<0.001*	0.52	<0.01*	0.92	0.4	<0.001*	0.44	0.9	



Above left: Highland plateau stretching over Kosciuzko National Park from Black Jack Mountain (adjacent to Maragle State Forest). Stags of predominantly Snow Gum *Eucalyptus pauciflora* remain after a wildfire in the 1970s.
Photography by B. Law.

Left centre: Cloud is a frequent feature of Alpine Ash *E. delegatensis* forest, growing here at 1 300 m, Maragle State Forest.
Photography by B. Law.

Below left: The Great Pipistrelle *Falsistrellus tasmaniensis* is listed as Vulnerable under the New South Wales *Threatened Species Conservation Act 1995,* but was recorded relatively frequently in high altitude forests of the south-west slopes.
Photography by B. Law.

Above right: Dry open forest and woodland predominates at lower, drier altitudes of the western slopes. Cockatoo Creek, Woomargama State Forest.
Photography by B. Law.

Right centre: Outside of State Forests, much of the native vegetation of the south-west slopes has been cleared for agriculture. Small remnants that still remain on private land form an important conservation resource.
Photography by B. Law.

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